AN ENERGY BUDGET FOR A HYPOTHETICAL BIOMASS PLANTATION

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Any fuel production process is sensitive to energy expenditure, since its net value as a productive process must be determined by weighing the quantity of energy produced against the quantity consumed during the process. A coal mining process, for example, must deliver more energy in the form of coal than it consumes in coal equivalents during the process of mining and transporting the coal. As long as the net balance is sufficiently in favor of energy capture, the process is worthwhile. If the balance should swing in favor of fuel or energy consumption, the coal is better left in the ground, other things being equal. The solar energy used to manufacture the organic raw material for the coal and the geologic pressures that combined through the ages to transform that material into coal need not be considered in the energy budget. The expenditure of these energies was circumstantial to man's need for or his ability to use the end product and therefore is circumstantial to the process.

The value of plant biomass production for use as an energy feedstock must also be evaluated on the basis of its energy budget. The production and collection of plant biomass require energy expenditure, which must be weighed against the energy value of the biomass produced to determine the net value of the process. If the input required is greater than the energy equivalent that can be harvested, the biomass is better left in the seed. As in the case of coal, the solar energy input need not be considered as energy expended, for in spite of its critical role in plant biomass production its advent is circumstantial to man's capability to utilize biomass. Likewise, the calorific or physiological energy consumed by human labor during the process is also discounted, since it is assumed that the laborers would consume that energy regardless of where or whether they labored.

To determine the energy budget for biomass production it is first necessary to estimate the energy value of the anticipated biomass yield. A yield of 30 dry tons per acre-year has been suggested as a realistic figure, providing that an adequate developmental research program is initiated. The energy captured in 30 dry tons is 450 million Btu, assuming a heating value of 7,500 Btu per dry pound.

Next, energy consumption must be estimated. This task requires, first, that a biomass farming system be visualized, then that the energy consuming operations that mediate the system be specified, and finally that the energy consumed in each of the operations be determined, and their sum calculated.

The biomass production system envisaged is the formal biomass plantation. The objective of the plantation would be to produce through intensive farming practices the greatest amount of biomass possible per unit time-space, at the lowest possible cost, and with a minimum of energy expenditure.

Conceptualization of the Plantation

A biomass plantation would be relatively large in terms of conventional agriculture, covering perhaps an area 15 miles square (144,000 acres). A facility for converting the biomass to usable energy (e.g., electric power plant, gasification plant) would be located at the center of the plantation. The biomass crop would consist of a conglomerate of species selected primarily on the basis of high biomass yield. The biomass crops with the highest yields would be located in the center of the plantation to reduce the costs of transportation of dried biomass from the drying areas to the conversion facility. Lower yielding species, such as short-rotation hardwoods, would be located at the fringes of the plantation or perhaps in certain sections of the plantation on land that was marginal for agricultural production. Each species would be cultivated in accordance with optimum planting, harvesting, and rotation schedules as determined in earlier field testing programs. Schedules would entail multiple cropping of annuals and multiple harvesting of perennials. Individual crop schedules would be integrated to provide as nearly as possible a continuous supply of biomass to the conversion facility. Conventional farming practices would be used where appropriate or modified to exploit either production potential or energy-costs savings to the fullest extent possible. Examples of such modifications would be the use of "no-till" methods, the harvest of roots and crowns in addition to aerial plant parts (annual crops), and the use of understory or shade-loving crops capable of full growth and development beneath the canopies of the primary biomass crops. Sun-drying of harvested biomass would be accomplished at strategically located drying areas. Yields of 30 tons of dry biomass per acre-year would be anticipated.

The plantation operation ideally would produce three crops of annuals per year or a harvest of perennial crops three times per year. Assuming the use of no-till methods, the following sequence of field tasks is envisaged.

Before planting, the fields would be cleared of weeds by the application of an herbicide to eliminate competition for light, water, and plant nutrients. Planting the biomass crop could be combined in one operation with the application of fertilizer. At an appropriate interval after planting, a sidedressing of fertilizer would be applied, although it should be possible to apply additional fertilizer with the irrigation water. The biomass crop would be harvested by means of self-propelled combines, which would chop the biomass into small pieces to facilitate drying. The chopped biomass would then be trucked to one of several drying areas on the plantation and dumped, whereupon a truck or similar vehicle fitted with a front-end blade would turn the piles of biomass until sufficient drying had occurred. The sun-dried biomass would then be loaded into suitable conveyances for transport to the plant gate. The schedule of field tasks would be repeated three times each year for annual crops such as sunflower or kenaf. In the case of perennial crops, replanting would be necessary only once every three to five years, even though the aerial portions of the crop were harvested three times each year. Short rotation hardwood species would be harvested once every one to three years, during the winter months only.

Aircraft would apply insecticides and fungicides when and where needed, the number of applications depending on the crops grown and the severity of their associated pest problems. It is assumed that an average of two such operations per acre-year would be needed across the entire plantation.

Irrigation water would be applied at two-week intervals by an automatic center-pivot overhead sprinkling system capable of watering two 160-acre plots per 24-hour day. The system could be moved as needed, requiring about three hours for each changeover. It is calculated that two and one-third systems would be needed to irrigate each 10,000 acres of the plantation. The plantation may be pictured as being located in the southwestern United States, where conditions would be the most conducive to year-round production and air-drying of the biomass.

The plantation would be operated seven days per week, 12 hours per day. Irrigation activities would be performed 24 hours per day.

This system was chosen as a study example because:

- It represents the ultimate in an organized approach to biomass production and collection.
- It is the system by which the largest yields can be realized in units of biomass produced per unit of time and space.
- It is the most energy intensive system in regard to the energy input required that can be visualized at this time, representing perhaps a worst case situation.

The energy consuming operations constituting the system are those concerned, either directly or indirectly, with biomass growing and harvesting. These would include not only such operations as field tasks, which are direct users of fossil fuel energy or consumers of electrical power on the plantation proper, but also the manufacturing processes for all equipment and materials used in the field tasks.

A discussion of energy consumption on the hypothetical plantation is presented below under the categories of direct fuel and power usage, farm chemicals manufacture, and farm machinery manufacture.

Direct Fuel and Power Usage

The technique for producing energy feedstock would naturally be chosen with energy conservation in mind. Hence, the practice of no-till farming, which requires a minimum of energy expenditure in the field, is considered a reasonable and realistic choice for the biomass plantation. The sequence of field tasks was described earlier. The energy consumed in direct fuel and power usage is shown in Table 1.

With the multiple cropping of annuals in mind, it is envisioned that this sequence of operations would be repeated three times each year, yielding an annual total of 30 tons of dry plant biomass per acre. In the case of perennial crops, it is apparent that certain operations, such as herbicide application and replanting, would not have to be performed three times each year even though three harvests per year were reaped. Hence, for crops such as Sudangrass, sugar cane and forage sorghums, the energy expended might be somewhat less than that shown in Table 1.

Irrigation water would be applied at a rate of four acre-feet per acre-year by means of an automated sprinkling system, probably of the center-pivot design. It is assumed that the water would be lifted from a network of surface canals to an average head of 50 feet, requiring 77 kWh of electric power per acre-foot dispensed. Miscellaneous electric power required for lighting of service road intersections and other purposes is estimated to be 5 kWh per acre-year for the plantation

Farm Chemicals Manufacture

It is estimated that 600 pounds nitrogen as anhydrous ammonia or its equivalent would be needed per acre-year to obtain yields approaching 30 tons per acre. This amount is two to five times that used in normal crop production. It is assumed that 250 lhs of phosphorus and 100 lbs potassium fertilizers per acre would be needed. Pesticides would be applied at recommended rates as needed. It is assumed that six pounds of herbicide, three pounds of insecticide, and two pounds of fungicide would be sufficient for each acre, since in all likelihood the pesticide needs of a biomass crop would be fewer than those of a conventional cash crop. Insecticides and fungicides, for example, would be needed only when pest infestations or infections became severe enough to restrict biomass production or to significantly reduce the amount of biomass already present in the field. Continuous cropping would also reduce the need for herbicides, especially if high plant densities were used to provide for early canopy closure, resulting in the "shading out" of weeds. The energy consumed in farm chemical manufacture is shown in Table 2.

Farm Machinery Manufacture

The energy expended in the manufacture of farm machinery from the mining of ore to the fabrication of the machinery itself depends on the volume and variety of implements needed for the plantation and their life expectancy. Calculations of the equipment needed to farm one acre, yielding 30 tons per acre-year, were based on a 12-hour workday, a seven-day week, and on the time required for each operation to be performed over 10,000 acres. Calculations of the time required for individual operations revealed that a three-tractor team could:

- Apply herbicide over 10,000 acres in 33 days.
- Plant and fertilize in 36.3 days.
- Fertilize in 33 days, and harvest (cut and chop) 10,000 acres in 26.5 days (with a six-combine team).

These time requirements were found to be compatible with a triple cropping schedule provided that 2 three-tractor teams were used. The number of fresh haul units needed was calculated on the basis of the need to haul the fresh biomass to a drying area within the same time period required by a six-combine team to harvest the biomass. Dry-haul requirements were also calcultaed on this basis. The life expectancey of each piece of equipment was calculated on the basis of a triple cropping schedule. It was assumed that each implement was composed entirely of steel produced from virgin ore. Use of scrap metal as the raw material would reduce the energy requirement in this category by approximately three-fourths. Since the energy required for production of forged steel is greater than that for cold-rolled steel components, it was assumed that the machinery composition was 50 percent forged steel and 50 percent cold-rolled steel. The weight of equipment in tons per year needed to farm 10,000 acres was calculated and multiplied by the appropriate energy factors to determine the energy input for 10,000 acres. The average energy input per acre-year was then calculated, as shown in Table 3.

Table 4 shows that the total energy input for all operations and fabrication is estimated to be about 22.0 million Btu per acre-year. If the energy output is 450 million Btu per acre-year, a net energy capture of about 428 million Btu per acre-year is realized. Thus, dividing gross energy yield by energy consumed results in an efficiency factor of 20.5 for energy capture by the plantation process. This factor would increase with increasing yields over 30 tons per acre-year or with the realization of additional energy economies through the further development of energy conservation practices on the plantation or in manufacturing processes. Conversely, this factor would be decreased by yields lower than 30 tons per acre-year or by the consumption of energy in related processes such as interbasin water transfer.

Table 1

ENERGY CONSUMED IN BIOMASS PLANTATION OPERATIONS
-Direct Fuel and Power Usage-

Operation	Rate per Operation*	Operations per Year	10^6 Btu per Acre-Year
Herbicide Application	0.305 gal dsl/acre	3	0.127
Plant and Fertilize	0.757 gal dsl/acre	3	0.315
Fertilize	0.305 gal dsl/acre	3	0.127
Harvest	1.627 gal dsl/acre	3	0.677
Fresh Haul	2.540 gal dsl/acre	3	1.057
Turn and Dry	0.028 gal dsl/acre	3	0.012
Dry Haul	2.178 gal dsl/acre	3	0.906
Pesticide Application	0.017 gal avt'n fuel/acre	2	0.007
Irrigation	77 KWh/acre-foot	4	3.154
Misc. Electricity	5 KWh/acre-year	1	0.051
Total Direct Fuel and Power Usage			6.433×10^6 Btu/Acre-Year

*Source: Doane's Agricultural Report. Nebraska Tractor Tests, 1969-1971.

Table 2

ENERGY CONSUMED IN BIOMASS PLANTATION OPERATIONS
-Farm Chemicals Manufacture-

Chemical	Rate/Acre-Year	Btu/lb	10^6 Btu/Acre-Year
Anhydrous Ammonia (NH_3)	600 lbs	19,341*	11.605
Phosphorus (P_2O_5)	250 lbs	6,019**	1.505
Potassium (K_2O)	100 lbs	4,158**	0.416
Herbicide	6 lbs	43,560**	0.261
Insecticide	3 lbs	43,560**	0.131
Fungicide	2 lbs	43,560**	0.087
Total Farm Chemicals Manufacture			14.005×10^6 Btu/Acre-Year

* Source: Hoeft, R. G., and J. C. Siemans, 1975. Do fertilizers waste energy? Crops and Soils, November 1975.

** Source: Pimentel, D., *et al.*, 1973. Food production and the energy crisis. Science 182:443-449.

Table 3

ENERGY CONSUMED IN BIOMASS PLANTATION OPERATIONS
-Farm Machinery Manufacture (10,000 acres)-

Machinery	Units	Unit Life (Years)	Steel per* Acre-Year (lbs)	Btu/Acre-Year
Tractors	6	6	0.92	88,854
Planters	3	2	0.60	57,948
Fertilizer Rigs	3	2	0.60	57,948
Herbicide Rigs	3	5	0.12	11,590
Harvesters	6	6	1.60	154,528
Fresh Haul Trucks	32	10	3.20	309,056
Dry Haul Trucks	10	10	1.20	115,896
Turner	1	10	0.10	9,658
Irrigation Pumps	8	20	0.08	7,726
Feeder Lines	30.6 mi	20	4.04	390,183
Sprinkler System	1	20	0.34	32,837
Total Farm Machinery Manufacture				1.236×10^6 Btu/Acre-Year

* 9.4325 KWh/lb;96,580 Btu/lb.

Source: Berry, R. S. and Margaret F. Fels, 1972. The production and consumption of automobiles. An energy analysis of the manufacture, discard and reuse of the automobile and it's component materials. A report to the Illionis Institute for Environmental Quality.

Table 4

ENERGY CONSUMED IN BIOMASS PLANTATION OPERATIONS
-Summary-

Consumption Category	Btu/Acre-Year	% Total Consumption
Direct Fuel and Power	6.433×10^6	29.4
Farm Chemicals Manufacture	14.005×10^6	64.0
Farm Machinery Manufacture	1.236×10^6	5.6
Seed or Rootstock Production	0.217×10^6	1.0
Total Plantation Energy Consumption	21.9×10^6	100.0
Total Plantation Energy Production	450.0×10^6	
Energy Input/Energy Output	1:20.5	